REMARKS

By this Amendment, a substitute specification is submitted herewith. No new matter has been added.

The Commissioner is hereby authorized to charge to Deposit Account No. 50-1165 (T2191-908028US01) any fees under 37 C.F.R. §§ 1.16 and 1.17 that may be required by this paper and to credit any overpayment to that Account. If any extension of time is required in connection with the filing of this paper and has not been separately requested, such extension is hereby requested.

Respectfully submitted,

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THERMIONIC ELECTRIC CONVERTER

FIELD OF THE INVENTION

The present invention relates generally to the field of converting heat energy directly to electrical energy. More particularly, a thermionic electric converter is provided.

BACKGROUND OF THE INVENTION

Heretofore, there have been known thermionic converters such as those shown in U.S. Pat. Nos. 3,519,854, 3,328,611, 4,303,845, 4,323,808, 5,459,367, 5,780,954 and 5,942,834 (all to the inventor of the present invention and all hereby incorporated by reference), which disclose various apparatus and methods for the direct conversion of thermal energy to electrical energy. In U.S. Pat. No. 3,519,854, there is described a converter using Hall effect techniques as the output current collection means. The '854 patent teaches use of a stream of electrons boiled off of an emissive cathode surface as the source of electrons. The electrons are accelerated toward an anode positioned beyond the Hall effect transducer. The anode of the '854 patent is a simple metallic plate, which has a heavily static charged member circling the plate and insulated from it.

U.S. Pat. No. 3,328,611 discloses a spherically configured thermionic converter, wherein a spherical emissive cathode is supplied with heat, thereby emitting electrons to a concentrically positioned, spherical anode under the influence of a control member, the spherical anode having a high positive

potential thereon and insulated from the control member. As with the '854 patent, the anode of the '611 patent is simply a metallic surface.

U.S. Pat. No. 4,303,845 discloses a thermionic converter wherein the electron stream from the cathode passes through an air core induction coil located within a transverse magnetic field, thereby generating an EMF in the induction coil by interaction of the electron stream with the transverse magnetic field. The anode of the '845 patent also comprises a metallic plate which has a heavily static charged member circling the plate and insulated from it.

U.S. Pat. No. 4,323,808 discloses a laser-excited thermionic converter that is very similar to the thermionic converter disclosed in the '845 patent. The main difference is that the '808 patent discloses using a laser which is applied to a grid on which electrons are collected at the same time the potential to the grid is removed, thereby creating electron boluses that are accelerated toward the anode through an air core induction coil located within a transverse magnetic field. The anode of the '808 patent is the same as that disclosed in the '845 patent, i.e., simply a metallic plate which has a heavily static charged member circling the plate and insulated from it.

U.S. Pat. No. 5,459,367 advantageously uses an improved collector element with an anode having copper wool fibers and copper sulfate gel instead of a metallic plate. Additionally, the collector element has a highly charged (i.e., static electricity) member surrounding the anode and insulated from it.

U.S. Patent Nos. 5,780,954 and 5,942,834 are directed to the provision of a cathode that is constructed as a wire grid, with the cathode being of a non-planar shape to increase its emissive surface area. These patents also disclose the technique of using a laser to hit the stream of electrons before they reach the anode, as a measure of providing quantum interference such that the electronics may be more readily captured by the anode.

Another prior design has an anode and cathode which are relatively close together such as two microns apart within a vacuum chamber. Such a prior design uses no attractive force to attract electrons emitted from the cathode to the anode other than induction of cesium into the chamber housing the anode and cathode. The cesium coats the anode with a positive charge to keep the electrons flowing. With the cathode and anode so close together, it is difficult to maintain the temperatures of the cathode and anode at substantially different temperatures. For example, one would normally have the cathode at 1800 degrees Kelvin and the anode at 800 degrees Kelvin. A heat source is provided to heat the cathode and a coolant circulation system is provided at the anode in order to maintain it at the desired temperature. Even though the chamber is maintained at a vacuum (other than the cesium source), heat from the cathode goes to the anode and it takes a significant amount of energy to maintain the high temperature differential between the closely spaced cathode and anode. This in turn lowers the efficiency of the system substantially.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a thermionic

converter having enhanced and/or improved features over those previously designed or developed.

A further principal object of the present invention is provide a thermionic electric converter with improved conversion efficiency.

Another object of the present invention is to provide an improved cathode for a thermionic electric converter having an increased cathode output.

Yet another object of the present invention is to provide a thermionic electric converter in which the cathode is bombarded by a laser to increase the emissivity of the cathode.

A further object of the invention is to provide an anode or target designed to capture electrons emitted from the cathode, while also accommodating a laser cathode enhancer.

The above and other objects of the present invention, which will be apparent as the description proceeds, are realized by a thermionic electric converter having a casing member, a cathode within the casing member operable when heated to serve as a source of electrons, and an anode within the casing member operable to receive electrons emitted from the cathode. The cathode may be a wire grid having wires going in at least two directions that are transverse to each other. A charged first focusing ring is in the casing member, between the cathode and the anode, and is operable to direct

electrons emitted by the cathode through the first focusing ring on their way to the anode. A charged second focusing ring is in the casing member, between the first focusing ring and the anode, and is operable to direct electrons emitted by the cathode through the second focusing ring on their way to the anode. Additional focusing rings may be necessary. The cathode is preferably separated from the anode at a distance between about 4 microns to about five centimeters. More preferably, the cathode is separated from the anode by a distance of one to three centimeters. A laser operable to hit electrons (i.e., apply a laser beam to the electrons) is positioned between the cathode and anode. The laser hits the electrons just before they reach the anode. The laser is operable to provide quantum interference with the electrons such that electrons are more readily captured by the anode.

The cathode may be either a solid material or formed of a wire grid. When the wire grid construction is used, the wire grid preferably includes at least four layers of wires. Further, each of the wire layers has wires extending in a different direction from each of the other of the wire layers, the wire grid of the cathode thus including wires extending in at least four different directions. This is designed to greatly increase the emissive surface of the cathode.

The present invention may alternately be described as a thermionic electric converter having a casing member, a cathode within the casing member operable when heated to serve as a source of electrons, an anode within the casing member operable to receive electrons emitted from the cathode; and a laser operable to hit electrons between the cathode and anode. The laser thus

provides quantum interference with the electrons such that electrons are more readily captured by the anode. The laser is operable to hit electrons just before they reach the anode. The laser is operable to hit electrons within 2 microns of when they reach the anode. The cathode is a wire grid having wires going in at least two directions that are transverse to each other. The cathode is separated from the anode at a distance of about 4 microns to about five centimeters.

The present invention may alternately be described as a thermionic electric converter having a casing member, a cathode within the casing member operable when heated to serve as a source of electrons, and an anode within the casing member operable to receive electrons emitted from the cathode and which proceed generally along a movement direction defining the direction from the cathode to the anode. The cathode has a planar cross section area normal to the movement direction, the cathode has an electron emission surface area for electron emission towards the anode, and the electron emission surface area is at least 30 percent greater than the planar cross section area. The cathode is a wire grid having wires going in at least two directions that are transverse to each other. Alternately, or additionally, the cathode is curved in at least one direction perpendicular to the movement direction. A laser is positioned so as to be operable to hit electrons between the cathode and anode just before they reach the anode. Preferably, the electron emission surface area is at least double the planar cross section area. More preferably, the electron emission surface area is at least double

the planar cross section area. The smaller the diameter of the wire, the larger the emissive area. This is an expotential relationship.

The present invention also involves the use of a laser positioned to impinge upon the cathode while being rastered or stepped along the cathode emissive surface, for the purpose of enhancing the output of electrons emitted from the cathode. The laser may be positioned behind the anode or target and aimed at the cathode, and the laser beam may be emitted through an opening in the target to impinge on the cathode. A target or anode specially designed to have an opening therein, preferably through the center thereof, is provided to accommodate the operation of the laser.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in detail herein with reference to the following figures in which like reference numerals denote like elements, and wherein:

FIG. 1 is a schematic diagram of a prior art thermionic electric converter;

FIG. 2 is a schematic diagram of a prior art laser-excited thermionic electric converter;

FIG. 3 is a side view with parts in cross section and schematic diagram of a thermionic electric converter according to the present invention;

FIG. 4 is a top view of a wire grid structure used for a cathode;

FIG. 5 is a side view of a part of the wire grid structure;

FIG. 6 is a side view of a part of an alternate wire grid structure;

FIG. 7 is a side schematic diagram illustrating multiple layers in a wire grid

structure; and

FIG. 8 is a simplified side view of an alternate cathode structure.

FIG. 9 is a side view with parts in cross-section and schematic diagram of a thermionic converter according to another preferred embodiment of the present invention.

FIG. 10 is a substantially schematic front elevation view of the target subassembly employed in the FIG. 9 embodiment.

FIG. 11 is a substantially schematic side view of the target subassembly of FIG. 10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. 1 and 2 show prior art thermionic electric converters as shown and described in U.S. Pat. Nos. 4,303,845 and 4,323,808, respectively, both to Edwin D. Davis, the inventor of the present invention, the disclosures of which are incorporated by reference herein in their entirety. While the operation of both thermionic converters is described in detail in the incorporated patents, a general operational overview is presented herein with reference to FIGS. 1 and 2. This may provide background useful in understanding the present invention.

FIG. 1 shows a basic thermionic electric converter. FIG. 2 shows a laser-excited thermionic converter. The operation of both converters is very similar.

With reference to the figures, a basic thermionic electric converter 10 is

shown. The converter 10 has an elongated, cylindrically shaped outer housing 12 fitted with a pair of end walls 14 and 16, thereby forming a closed chamber 18. The housing 12 is made of any of a number of known strong, electrically non-conductive materials, such as, for example, high-temperature plastics or ceramics, while the end walls 14, 16 are metallic plates to which electrical connections may be made. The elements are mechanically bonded together and hermetically sealed such that the chamber 18 may support a vacuum, and a moderately high electrical potential may be applied and maintained across the end walls 14 and 16.

The first end wall 14 contains a shaped cathode region 20 having an electron emissive coating disposed on its interior surface, while the second end wall 16 is formed as a circular, slightly convex surface which is first mounted in an insulating ring 21 to form an assembly, all of which is then mated to the housing 12. In use, the end walls 14 and 16 function respectively as the cathode terminal and the collecting plate of the converter 10. Between these two walls, an electron stream 22 will flow substantially along the axis of symmetry of the cylindrical chamber 18, originating at the cathode region 20 and terminating at the collecting plate 16.

An annular focusing element 24 is concentrically positioned within the chamber 18 at a location adjacent to the cathode 20. A baffle element 26 is concentrically positioned within the chamber 18 at a location adjacent to the collecting plate 16.

Disposed between these two elements is an induction assembly 28 comprised of a helical induction coil 30 and an elongated annular magnet 32. The coil 30 and the magnet 32 are concentrically disposed within, and occupy the central region of, the chamber 18. Referring briefly to the schematic view of FIG. 2, the relative radial positioning of the various elements and assemblies may be seen. For clarity of presentation, the mechanical retaining means for these interiorly located elements have not been included in either figure. Focusing element 24 is electrically connected by means of a lead 34 and a hermetically sealed feed through 36 to an external source of static potential (not shown). The induction coil 30 is similarly connected via a pair of leads 38 and 40 and a pair of feed-throughs 42 and 44 to an external load element shown simply as a resistor 46.

The potentials applied to the various elements are not explicitly shown nor discussed in detail as they constitute well known and conventional means for implementing related electron stream devices. Briefly, considering (conventionally) the cathode region 20 as a voltage reference level, a high, positive static charge is applied to the collecting plate 16 and the external circuit containing this voltage source is completed by connection of its negative side to the cathode 20. This applied high, positive static charge causes the electron stream 22 which originated at the cathode region 20 to be accelerated towards the collecting plate 16 with a magnitude directly dependent upon the magnitude of the high static charge applied. The electrons impinge upon the collecting plate 16 at a velocity sufficient to cause a certain amount of ricochet. The baffle element 26 is configured and

positioned to prevent these ricochet electrons from reaching the main section of the converter, and electrical connections (not shown) are applied thereto as required. A negative voltage of low to moderate level is applied to the focusing element 24 for focusing the electron stream 22 into a narrow beam. In operation, a heat source 48 (which could be derived from diverse sources such as combustion of fossil fuels, solar devices, atomic devices, atomic waste or heat exchangers from existing atomic operations) is used to heat the electron emissive coating on the cathode 20, thereby boiling off quantities of electrons. The released electrons are focused into a narrow beam by focusing element 24 and are accelerated towards the collecting plate 16. While transiting the induction assembly 28, the electrons come under the influence of the magnetic field produced by the magnet 32 and execute an interactive motion which causes an EMF to be induced in the turns of the induction coil 30. Actually, this induced EMF is the sum of a large number of individual electrons executing small circular current loops thereby developing a correspondingly large number of minute EMFs in each winding of the coil 30. Taken as a whole, the output voltage of the converter is proportional to the velocity of the electrons in transit, and the output current is dependent on the size and temperature of the electron source. The mechanism for the induced EMF may be explained in terms of the Lorentz force acting on an electron having an initial linear velocity as it enters a substantially uniform magnetic field orthogonally disposed to the electron velocity. In a properly configured device, a spiral electron path (not shown) results, which produces the desired net rate of change of flux as required by Faraday's law to produce an induced EMF.

This spiral electron path results from a combination of the linear translational path (longitudinal) due to the acceleration action of collecting plate 16 and a circular path (transverse) due to the interaction of the initial electron velocity and the transverse magnetic field of magnet 32. Depending on the relative magnitude of the high voltage applied to the collecting plate 16 and the strength and orientation of the magnetic field produced by the magnet 32, other mechanisms for producing a voltage directly in the induction coil 30 may be possible. The mechanism outlined above is suggested as an illustrative one only, and is not considered as the only operating mode available. All mechanisms, however, would result from various combinations of the applicable Lorentz and Faraday considerations.

The basic difference between the basic converter shown in U.S. Pat. No. 4,303,845 and the laser-excited converter shown in U.S. Pat. No. 4,323,808, is that the laser-excited converter collects electrons boiled off the surface of the cathode on a grid 176 having a small negative potential applied thereon by a negative potential source 178 through lead 180, which traps the electron flow and mass of electrons. The electrical potential imposed on the grid is removed, while the grid is simultaneously exposed to a laser pulse discharge from laser assembly 170, 173, 174, 20 causing a bolus of electrons 22 to be released. The electron bolus 22 is then electrically focused and directed through the interior of the air core induction coils located within a transverse magnetic field, thereby generating an EMF in the induction coil which is applied to an external circuit to perform work, as set forth above with respect

to the basic thermionic converter.

As set forth the present inventor's prior U.S. Pat. No. 5,459,367, there are numerous attendant disadvantages usually associated with having a collecting element simply made up of a conductive metal plate. Therefore, the collecting element of that design includes a conductive layer of copper sulfate gel impregnated with copper wool fibers. The present invention may use such an anode. However, the present invention also may use a conductive metal plate anode as other aspects of the present invention will minimize or avoid some of the disadvantages that such a plate anode might otherwise cause. Basically then, the specifics of the anode are not central to the preferred design of the present invention.

With reference now to FIG. 3, a thermionic electric converter 200 according to the present invention includes a casing member 202 in which a vacuum would be maintained by vacuum apparatus (not shown) in known fashion. The casing member 202 is preferably cylindrical about a central axis 202A which serves as an axis of symmetry of the member 202 and the components therein except where otherwise noted.

The collector 204 may include a flat anode circular plate 206 (made of copper for example) surrounded by a statically charged ring 208 (charged to 1000 Coulombs for example) having insulating rings 210 concentric therewith. The ring 208 and rings 210 may be constructed and operable as discussed in the U.S. Pat. No. 5,459,367. A cooling member 212 is thermally coupled to the

plate 206 such that coolant from coolant source 214 is recirculated therethrough by coolant circuit 216. The cooling member 212 maintains the anode plate at a desired temperature. The cooling member 212 may alternately be the same as the anode plate 206 (in other words coolant would circulate through plate 206). A feedback arrangement (not shown) using one or more sensors (not shown) could be used to stabilize the temperature of anode 206.

The cathode assembly 218 of the present invention includes a cathode 220 heated by a heat source such that it emits electrons which generally move along movement direction 202A towards the anode 206. (As in the U.S. Pat. No. 5,459,367, the charged ring 208 helps attract the electrons towards the anode.) Although the heat source is shown as a source 222 of heating fluid (liquid or gas) flowing to heating member 224 (which is thermally coupled to the cathode 220) via heating circuit 226, alternate energy sources such as a laser applied to the cathode 224 might be used. The energy input into source 222 could be fossil fuel, solar, laser, microwave, or radioactive materials. Further, used nuclear fuel that would otherwise simply be stored at great expense and without benefit might be used to provide the heat to source 222.

Electrons energized to the Fermi level in cathode 220 escape from the surface thereof and, attracted by static charge ring 208, travel along movement direction 202A through first and second focussing rings or cylinders 228 and 230, which may be constructed and operable in similar fashion focussing element 24 of the prior art arrangement discussed above. In

order to help the electrons move in the proper direction a shield 232 may surround the cathode 224. The shield 232 may be cylindrical or conical or, as shown, include a cylindrical portion closest the cathode 224 and a conical portion further from the cathode 224. In any case, the shield tends to keep electron movement in direction 202A. The electrons will tend to be repelled from the shield 232 since the shield will be at a relatively high temperature (from its proximity to the relatively high temperature cathode 220). Alternately, or additionally, to being repelled by the high temperature of the shield, the shield 232 could have a negative charge applied to it. In the latter case, insulation (not shown) could be used between the shield 232 and cathode 220.

The electrical energy produced corresponding to electron flow from cathode 220 to anode 206 is supplied via cathode wire 234 and anode wire 236 to an external circuit 238.

Turning from the overall operation of the converter 200 to specific advantageous aspects thereof, electrons such as electron 240 tend to have a high energy level as they approach the anode 206. Therefore, the normal tendency would be for some to bounce off the surface and not be captured therein. This normally results in electron scatter and diminishes the conversion efficiency of a converter. In order to avoid or greatly reduce this tendency, the present invention uses a laser 242 which hits the electrons (e.g., hits them with a laser beam 244) just before they hit the anode 206. The quantum interference between the photons of the laser beam 244 and the

electrons 240 drops the energy state of the electrons such that they are more readily captured by the surface of anode 206.

As will be understood from the dual wave-particle theory of physics, the electrons hit by the laser beam may be exhibiting properties of waves and/or particles. Of course, the scope of the claims of the present invention are not limited to any particular theory of operation unless and except where a claim expressly references such a theory of operation, such as quantum interference.

As used herein, when reference is made to the laser 242 hitting the electrons with beam 244 "just before" the electrons reach the anode 206 means that the electrons which have been hit do not pass through any other components (such as a focusing member) as they continue to the anode 206. More specifically, the electrons are preferably hit within 2 microns of when they reach the anode 206. Even more preferably, the electrons are hit by the laser with 1 micron of reaching the anode 206. Indeed, the distance from the second focusing element 230 to the anode 206 may be 1 micron and the laser may hit electrons closer to the anode 206. In that fashion (i.e., hitting the electrons just before they reach the anode), the energy of the electrons is reduced at a point where reduced energy is most appropriate and useful.

Although casing member 202 may be opaque, such as a metal member, a laser window 246 is made of transparent material such that the laser beam 244 can travel from laser 242 into the chamber within member 202.

Alternately, the laser 242 could be disposed in the chamber.

In addition to improving conversion efficiency by using the laser 242 to reduce the energy level of electrons just before they reach the anode 206, the cathode 220 of the present invention is specifically designed to improve efficiency by increasing the electron emission area of the cathode 220.

With reference to FIG. 4, the cathode 220 is shown as a circular grid of wires 248. Wires 250 of a top or first layer of parallel wires extend in direction 252, whereas wires 254 of a second layer of parallel wires extend in direction 256, transverse to direction 252 and preferably perpendicular to direction 252. A third layer of parallel wires (only one wire 258 shown for ease of illustration) extend in direction 260 (45 degrees from directions 252 and 256. A fourth layer of parallel wires (only one wire 262 shown for ease of illustration) extend in direction 264 (90 degrees from direction 260).

It should also be noted that FIG. 4 shows the wires with relatively large separation distances between them but this is also for ease of illustration. Preferably, the wires are finely extruded wires and the separation distances between parallel wires in the same layer would be similar to the diameter of the wires. Preferably, the wires have diameters of 2 mm or less to fine filament size. The wires may be tungsten or other metals used in cathodes.

With reference to FIG. 5, the wires 250 and 254 may be offset from each other with all wires 250 (only one shown in FIG. 5) disposed in a common

plane offset from a different common plane in which all wires 254 are disposed. An alternate arrangement shown in FIG. 6 has wires 250' (only one visible) and 254' which are interwoven in the manner of fabric.

With reference to FIG. 7, an alternate cathode 220' may have three portions 266, 268, and 270. Each of portions 266, 268, and 270 may have two perpendicular layers of wires (not shown in FIG. 7) such as 250 and 254 (or 250' and 254'). Portion 266 would have wires going into the plane of view of FIG. 7 and wires parallel to the plane of FIG. 7. Portion 268 has two layers of wires, each having wires extending in a direction 30 degrees from one of the directions of the wires for portion 266. Portion 270 has two layers of wires, each layer having wires extending in a direction 60 degrees from one of the directions of the wires for portion 266.

It will be appreciated that FIG. 7 is illustrative of the point that multiple layers of wires extending in different directions could be used.

The various wire grid structures for the cathode increase the effective electron emission surface area by way of the shape of the wires and their multiple layers. An alternative way of increasing the surface area is illustrated in FIG. 8. FIG. 8 shows a side cross section view of a parabolic cathode 280 operable to emit electrons for movement generally along movement direction 220A'. The cathode 280 has a planar cross section area A normal to the movement direction 202A. Significantly, the cathode 280 has an electron emission surface area EA (from the curvature of the cathode) for electron emission

towards the anode which is at least 30 percent greater than the planar cross section area A. Thus, a greater density of electrons are generated for a given size cathode. Although the cathode 280 is shown as a parabola, other curved surfaces may be used. The cathode 280 may be made of a solid member or may also incorporate multiple layer wire grid structures like described for FIGS. 4-7 except that each layer would be curved and not planar.

Although the curved cathode arrangement of FIG. 8 provides an electron emission surface area EA that is at least 30 percent greater than the side cross section area A, the various wire grid arrangements such as FIG. 4 provide an electron emission surface area that is at least double the side cross section area (i.e., defined as shown for FIG. 8). Indeed, the electron emission surface area in the grid arrangements should be at least ten times the side cross section area.

Advantageously, the present invention allows the cathode 220 and anode 206 to be offset from each other by from 4 microns to 5 cm. More specifically, that offset or separation distance will be from 1 to 3 cm. Thus, the cathode and anode are sufficiently far apart that heat from the cathode is less likely to be conveyed to the anode than in the arrangements where the cathode and anode must be in close proximity. Therefore, the coolant source 214 can be a relatively low coolant demand arrangement since less cooling is required than in many prior designs.

Turning now to FIGS. 9-11, a further embodiment of the thermionic electric

converter of the present invention is illustrated. This embodiment is designed to further increase the output of electrons from the cathode, thereby further increasing the conversion efficiency and electrical current generation of the converter.

The thermionic electric converter 300 according to the embodiment shown in FIGS. 9-11 may preferably employ many of the same or similar components to the converter 200 illustrated and described with respect to FIGS. 3-8. In particular, the converter 300 preferably includes a casing member 302, which may preferably be cylindrical along at least a portion of its longitudinal extent. The converter 300 further includes an electron target subassembly or collector 304, the constructional details of which will be discussed later. A cooling member 312 is provided to maintain the target subassembly 304, or specific components thereof, at a desired temperature, generally lower than an operating temperature of cathode subassembly 318. The cathode subassembly 318 preferably includes a cathode 320 having a cathode emitter 321, the cathode being heated by a heat source 322 thermally coupled to the cathode such that the heating of the cathode will cause electrons to become energized and escape from the surface of the cathode emitter 321.

The heat source 322, as illustrated, includes a heating member 324 coupled to the cathode, and a heating circuit 326 which delivers a heating fluid (liquid or gas) to cathode 320. As with the embodiments disclosed in FIGS. 3-8, it will be recognized by persons of ordinary skill in the art that the source of

thermal energy for heating the cathode from an external source may take the form of solar energy, fossil fuel, laser energy, microwave energy, or thermal energy derived from radioactive materials, such as radioactive waste or spent radioactive materials. Used nuclear fuel that would otherwise be required to be stored at great expense could be used to provide thermal energy for heat source 322. The construction of basic systems or subassemblies for providing the various types of thermal energy will be readily apparent to persons of ordinary skill in the art.

Converter 300 may also preferably employ first and second focusing rings 328, 330, in a manner similar to that shown in FIG. 3. A shield 332 may also be provided to surround cathode 320, to perform essentially the same function as does shield 232 in the FIG. 3 embodiment.

Electrical energy produced corresponding to an electron flow from cathode emitter 321 to anode 306 of target subassembly 304 is supplied via cathode wire 334 and anode wire 336 to an external circuit 338. Circuit 338 thus receives energy in electrical form, which energy is produced or generated from thermal energy by converter 300. Circuit 338 may preferably include a transistor 337 connected in the circuit return line (shown as cathode wire 334 in FIG. 9), so that the current in the circuit is restricted to flowing in only one direction, i.e., in the direction back to cathode emitter 321, via a feedthrough 339 in casing member 302.

The converter 300 further preferably includes an electron interference laser 342, which operates to lower the energy state of the electrons as they reach anode 306, as by quantum interference or other particle interaction phenomena. Laser beam 344 passes through laser window 346 and intersects the path of, or "hits", the incoming electrons to reduce the energy stored in the electrons. Reference may be had to the discussion of this aspect of the invention in connection with laser 242 and laser beam 244, and FIG. 3 herein, insofar as the theory of operation is concerned. The reduction in the energy level of the electrons immediately prior to contacting anode 306 decreases the tendency of electrons to hit anode 306 and to bounce off and scatter because of the collision. Anode 306 will thus capture a larger percentage of the incoming electrons.

Target subassembly or collector 304 is preferably constructed so as to have a central opening 370 sized and adapted to allow a cathode output enhancing device or auxiliary cathode enhancer 372, in the form or a laser 374, to emit a laser beam 376 in the direction 376a of the emitting surface 321 of cathode 320. Alternatively, target subassembly may have such an opening in an off-center location, or, alternatively, may be sized and positioned within casing member 302 such that laser 374 can direct laser beam 376 from a position outside the periphery of the target subassembly.

Referring to all of FIGS. 9-11, target subassembly 304 may preferably comprise an anode 306 having opening 370 therethrough, shown centrally in the drawing figures, for the sake of convenience. An insulating (electrically

insulating) ring 378 is positioned at an edge of opening 370, and is preferably secured to anode 306 at that edge. An electron repulsion ring 380 is disposed at an inner periphery of insulating ring 378. This repulsion ring 380 is provided in order to substantially prevent electrons emanating from cathode 320 and traveling along path 302a from passing into and through the opening defined by repulsion ring 380, or to minimize the number of electrons passing therethrough. Electron repulsion ring 380 is preferably provided with a negative charge imposed by an external source (not shown) coupled to the repulsion ring at feedthrough 379, or may operate in a different manner to repel electrons. Preferably, the ring 380 will operate to deflect at least portion of the electrons into a path that will result in the electrons colliding with anode 306 of target subassembly 304.

Anode 306 may be formed as a flat circular plate, as illustrated, or may alternatively be curved in either a direction toward or away from cathode 324, or otherwise shaped in a manner designed to effectively capture electrons traveling along paths from the cathode 320 into contact with the anode. Anode 306 preferably has, at its outer periphery, a highly statically charged, or Faraday, ring 308 bounded by inner and outer insulating rings 310. This portion of the target subassembly will be essentially the same as that disclosed with respect to the FIG. 3 embodiment, and will operate in generally the same manner, to aid in attracting the electrons toward anode 306, where the electrons can be collected in order to generate an electrical current. A feedthrough connector, shown schematically in FIG. 11 at 382, is employed to couple the Faraday ring 308 to a means for imparting the desired high static

charge. Insulating rings 310 operate to electrically insulate anode 306 and the main electrical circuit 338 from the static charge imposed on ring 308.

The plate anode 306 may be constructed of the same materials as is the anode 206 in FIG. 3, or may be of any other type known in the art to be suitable for this use. Cathode 320 may also be constructed of the same materials and in the same manner as is cathode 220 discussed and illustrated with respect to FIGS. 3-8, or any other cathode structure disclosed in the prior patents discussed in the Background section herein.

In the embodiment of FIGS. 9-11, the output of the cathode is greatly increased over that obtained in the embodiment shown in FIGS. 3-8. As noted previously, an auxiliary cathode enhancer 372, in the form of laser 374, is provided to direct a laser beam 376 at the emissive surface 321 of the cathode, which further excites the electrons on that surface, over and above the excitation obtained by the thermal energy supplied by heating source 322.

In the illustrated preferred embodiment, the laser 374 is positioned inside of casing member 302 and on a side of anode 306 opposite the side at which cathode 320 is positioned. Laser 374 is aimed to direct laser beam 376 such that the photons travel along path 376a in essentially the opposite direction of the path 302a of the electrons traveling from cathode 320 to anode 306. Laser beam 376 preferably strikes the emissive surface 321 of the cathode either orthogonally to that surface, or at a small angle of incidence thereto, to maximize the energy transfer to the electrons.

The laser 374 will preferably be controlled by controller 400 to emit "shots" or pulses having, for example, a duration on the order of one to several picoseconds, at a frequency of about 10-100 MHz. Other operational regimes may also be adopted, and it should be recognized that these parameters are provided primarily for illustrative purposes.

The auxiliary cathode enhancer 372 will also preferably include a rastering device, shown schematically at ~~382~~<u>384</u> in FIG. 11. The rastering device 382 will be controlled, preferably also by controller 400, to cause the laser beam 376 to sweep in both lateral (side-to-side) and vertical (up-to-down, or vice versa) directions, in a manner that will be readily apparent to persons skilled in the art upon reading this description. The rastering device ~~382~~<u>384</u> is used so as to prevent erosion of the emissive surface of the cathode 320 at regions where the laser beam might otherwise constantly or frequently impinge, thus prolonging the life of the cathode. The rastering device will preferably complete a sweep from side-to-side and from top to bottom of the cathode at a frequency on the order of one to several nanoseconds. Again, this period may differ from the stated preferred range, and may be coordinated with the frequency and duration of the laser pulses to provide different desired degrees of auxiliary excitation of the electrons at the cathode surface.

It is expected that the use of an auxiliary cathode enhancer of the type disclosed will increase the output of the cathode by approximately 20-25 times the output of the cathode in FIGS. 3-8, for example, when that converter is

operated without the auxiliary enhancer. Again, the operating parameters of the enhancer may be varied as desired to either increase or decrease the level of enhancement to the cathode output.

In FIG. 10, possible alternative positions for the laser 374 of the auxiliary cathode enhancer 372 are shown at A, B and C. These designations are intended to show that the laser 374 may be mounted off-center, relative to target subassembly 304, whereby the opening in the anode 306 would be off-center, or may be mounted outside the outer periphery of target subassembly 304. In this latter case, there would be no need to provide an opening in the anode, nor would an electron repulsion ring be necessary. As noted previously, it is desired to maintain a relatively small angle of incidence of the laser beam relative to the emissive surface 321 of the cathode, in order to maintain an efficient transfer of energy. The off-center positionings could possibly result in a less-efficient enhancement of cathode output, however, other design consideration may be simplified using such positions, which could compensate for the slightly lower efficiency.

Further, to this point, the discussion of the positioning of the laser has focused on positioning the laser at the back side of the target subassembly 304, opposite the side at which the cathode is positioned. While such positioning tends to maintain a smaller angle of incidence of the laser beam with respect to the cathode surface, it would be possible to position the laser 374 forward of the anode 306 (i.e., longitudinally between the anode and cathode),

provided it is positioned radially outside the path of the electrons traveling from the cathode to the anode.

A further feature of the invention illustrated in FIG. 11 is the provision of a plurality of electrets 398 around the inner periphery of casing member 302, to aid in scavenging any stray electrons that may bounce off of anode 306 or otherwise fail to be captured by the anode. Such stray electrons can create a space charge within the vacuum chamber. The electrets 398 will be connected to ground, so as to substantially prevent any space charge buildup.

While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention, as set forth herein, are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention as defined herein and in the following claims.